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Original article

Exploring Wind Energy Potentials in Yefran, Libya: A Technical Assessment Based on Speed Criteria

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Abstract
Electricity demand is increasing daily, posing a major challenge worldwide. Therefore, it is more crucial than ever to transition to clean, environmentally friendly renewable energy sources as an alternative to traditional fossil fuel-based power generation. Wind energy is one such renewable energy source that offers a clean solution for electricity generation. This study aims to estimate the potential wind power based on the collection of wind speed data using a suitable method of the Weibull parameter, where wind data is collected from the National Center for Meteorology for 2018–2020 based on their in the Yefran region. An important conclusion is that the highest average monthly wind speeds were recorded in March 2018 and December 2020, reaching 10.9 knots (5.607 m/s) in both. On the other hand, the lowest wind speeds were recorded in February 2019 saw the quietest period with an average wind speed of 6.4 knots (3.292 m/s). In general, Wind speeds remained relatively stable over the three years, with 2020 being the most active year in terms of wind speed. Also, in 2018, the unoptimized model predicted an output of 999,046.18 kWh, while the Weibull model revised this value to 1,749,812.56 kWh (+75.15%). The most interesting finding in the data is the high volatility in 2019. According to the unoptimized model, 2019 appeared to be the worst year (907,395.64 kWh). However, according to the Weibull model, it actually became the highest-yielding year (1,863,640.40 kWh), resulting in a massive variance of +105.38%. In 2020, the winds were stable and regular, with 2020 experiencing the lowest variability (+70.39%), as production increased from 1,031,737.83 kWh to 1,757,987.35 kWh.
Keywords: Wind speed, Yefran city, Renewable energy, Weibull distribution.

Introduction

The role of electricity is crucial for societal development, as it fosters economic growth. It plays a fundamental role in industries, human life, and numerous applications of human development, such as computers, smartphones, and factories. Global warming and the scarcity of fossil fuels are forcing humanity to search for cleaner and cheaper energy sources (1). When it comes to supporting social development and mitigating the effects of fossil fuel use, renewable energy sources are a viable alternative. Renewable energy sources have now reached a level of development that justifies their commercial exploitation (2). Wind energy is the kinetic energy of moving air masses in the Earth's atmosphere, and it is one of the most dynamic climatic elements (spatially and temporally), as it expresses the barium variation resulting from the general circulation of the atmosphere (3). As we all know, wind energy, like solar energy, is subject to seasonal weather changes, which depend on the shifts and changes that occur over time in the general circulation of the atmosphere (4).

In recent years, wind energy has proven to have enormous potential for further development. Wind is abundant and free, making it an excellent alternative and option for stabilizing and standardizing energy costs globally [5]. It also allows for avoiding the costs associated with fossil fuels and redirecting available funds towards other development programs [5]. Due to recent advancements in wind turbine technology, it has become possible to generate large quantities of electricity, and these turbines are highly sensitive to changes in wind speed [6]. Therefore, the viability of any project depends critically on the wind resources at the site to be developed. Consequently, wind resource assessment studies must be conducted at the outset of any wind energy project, as the long-term average wind speed at the proposed site is unknown. This study proposes a sound assessment of wind energy resources and presents an example of its application in Yefren, Libya. This location's climate is enriched with an abundance of solar energy potential.

Literature review

Weibull Distribution

One of the key and important criteria to consider is wind speed distribution, which describes the amount of time the wind speed fluctuates between different levels at a given location. Combining wind speed distribution with the power curve of a proposed wind turbine determines the energy output of a wind power system (7). The Weibull distribution has proven effective in describing wind speed variations and is widely used in modeling such data (8,9,10). Since wind speed data are typically stored as time series, it makes sense to use the Weibull distribution to summarize information from large wind speed datasets into estimates of multiple parameters. This research will focus on estimating the parameters of wind speed data. Since the Weibull distribution is a mathematical expression that provides a good approximation of many measured wind speed distributions, it is frequently used to characterize locations. Here, it relies on two related criteria that describe the Weibull distribution [11, 12, 13]:

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I. Shape factor α or k: This is a measure of the width of the distribution. Its value often ranges between 1.5 and 3.0 in most wind conditions. There is also a special type of Weibull distribution called the "Rayleigh distribution" in which the shape factor is 2.0, and it is commonly used by wind turbine manufacturers to characterize turbines.

II. Scale factor β or λ: This is closely related to the average wind speed and also depends on the value of the shape factor through the following function:

$$v_m = \lambda \Gamma \left(1 + \frac{1}{k}\right) \qquad (1)$$

$$f(t) = 1 - exp\left[-\left(\frac{v}{\lambda}\right)^k\right] \qquad (2)$$

Methodology

Location of the study

The National Center for Meteorology installed some measurements of wind speed at different locations in Libya. The researcher chose Yefran City to apply their study, according to data collected by the National Center for Meteorology. Yefran is located in northwestern Libya, situated within the Nafusa Mountains region. It sits approximately 130 kilometers (80 miles) southwest of the capital city, Tripoli, and sits at an elevation of approximately 670 to 700 meters above sea level. Figure 1. The prospective wind power locations in Yefran City.

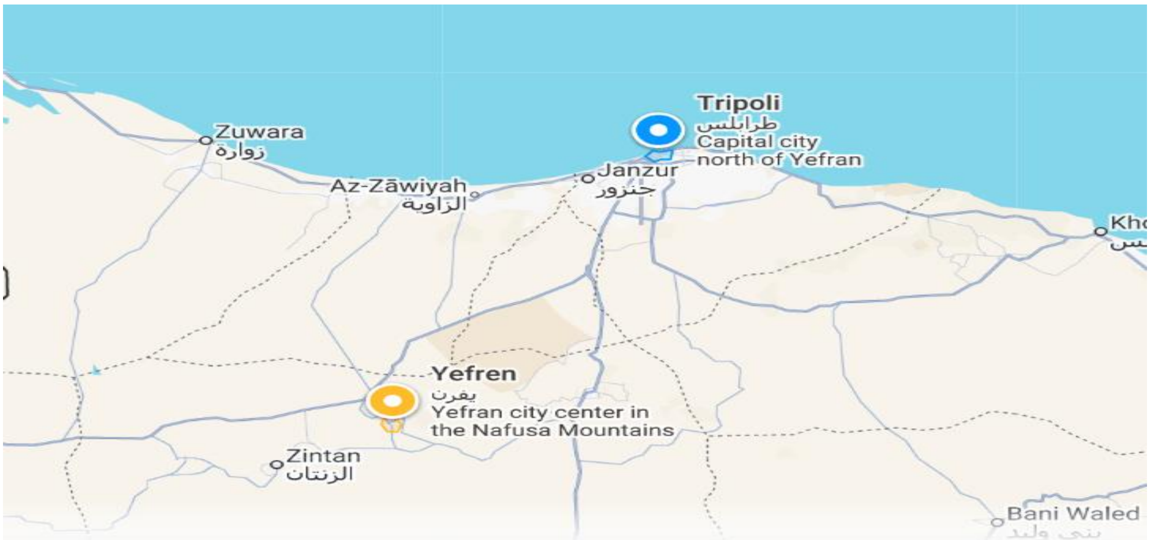

Figure 1. The prospective wind power locations in Yefran City

Data collection

Wind speed data were obtained from the National Center of Meteorology, and wind speeds were recorded throughout the day. Monthly wind speeds were calculated in knots and meters per second as shown in Table 1. To convert wind speed from knots (kt) to meters per second (m/s), use the exact multiplier (0.514444). Since all monthly wind speeds fall safely within your operational limits ($3\ m/s \leq \boldsymbol{v} \leq 25\ m/s$), the aerodynamic power in kilowatts (kW) for each month.

$$Vm/s = Vkt \times 0.514444 \qquad (3)$$

Where: Vm/s - is the wind speed in meters per second.

Vkt - is the wind speed in knots.

Table 1. The values of wind speed in knots and m/s.

Month	2018		2019		2020	
	Wind Speed		Wind Speed		Wind Speed	
	Knot	M/S	Knot	M/S	Knot	M/S
JAN	9.8	5.041	10.2	5.247	10.2	5.247
FEB	10.3	5.298	6.4	3.292	7.0	3.601
MAR	10.9	5.607	8.3	4.270	9.8	5.041
APR	9.9	5.093	9.7	4.990	10.1	5.195
MAY	9.7	4.990	9.4	4.835	10.2	5.247
JUN	8.7	4.475	9.2	4.732	10.0	5.144
JUL	7.9	4.064	7.9	4.0064	8.2	4.218
AUG	7.8	4.012	8.3	4.270	8.5	4.372
SEP	8.5	4.372	7.3	3.755	8.9	4.578
OCT	9.4	4.835	8.7	4.475	8.6	4.424

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NOV	9.3	4.784	9.9	5.093	8.1	4.167
DEC	7.2	3.704	10.3	5.298	10.9	5.607
Average						

As shown in Table 1 and Figure 2, the highest average monthly wind speeds were recorded in March 2018 and December 2020, reaching 10.9 knots (5.607 m/s) in both. On the other hand, the lowest wind speeds were in February 2019 saw the quietest period with an average wind speed of 6.4 knots (3.292 m/s). In general, Wind speeds remained relatively stable over the three years, with 2020 being the most active year in terms of wind speed.

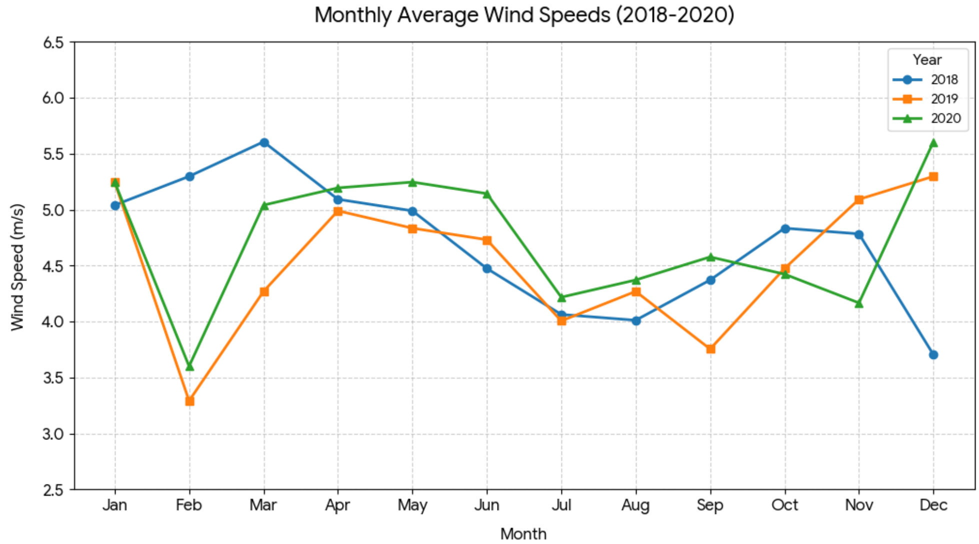

Figure 2. Monthly Average wind speeds (2018 to 2020)

Code used in this study to measure wind speed

```
clc;
% 1. Turbine Parameters
rho = 1.225;            % Air density (kg/m^3)
radius = 40;            % Blade radius (m)
A = pi * radius^2;      % Swept area
Cp = 0.35;              % Power coefficient
cut_in = 3;             % Cut-in wind speed (m/s)
cut_out = 25;           % Cut-out wind speed (m/s)

year2018 = 0.5144*[9.8 10.3 10.9 9.9 9.7 8.7 7.9 7.8 8.5 9.4 9.3 7.2];

% 2. Generate one-year monthly wind speed data

% hours_total = 365 * 24;
% % Synthesizing a normally distributed wind speed profile for example
% mean_wind = 7;
% std_dev = 3;
wind_speeds = year2018
% Ensure no negative wind speeds
wind_speeds(wind_speeds < 0) = 0;

% 3. Calculate Power and Energy
energy_kwh = zeros(12, 1);

for i = 1:12
  v = wind_speeds(i);

  % Check operational wind speed range
  if v >= cut_in && v <= cut_out
    % Power formula returns Watts, divide by 1000 for kW
    power_w = 0.5 * rho * A * Cp * (v^3);
```


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```
      power_kw = power_w / 1000;
    else
      power_kw = 0;
    end

    % Energy = Power (kW) * time (one moth in hours)
    energy_kwh(i) = power_kw * 1*30*24;
   % energy_wh(i) = power_w * 1;
end
energy_kwh
% 4. Total Results
total_energyk_2018 = sum(energy_kwh);
%total_energyw_2018 = sum(energy_wh);
fprintf('Total energy produced in 2020: %.2f kWh\n', total_energyk_2018);

months=[1:12];
plot(months,energy_kwh);
grid
xlabel('Months')
```

Results of wind energy by using MATLAB software

Table 2 shows the monthly energy production (in kilowatt-hours, kWh) derived from previously analyzed wind speed data, illustrating how wind speed translates directly into usable electrical energy. Because wind turbine energy production is directly proportional to wind speed, your energy output accurately reflects the peaks, dips, and anomalies in the wind speed table.

Table 2. Monthly energy production (in kilowatt-hours, kWh) derived from analyzed wind speed data

Month	Monthly Energy Output (kWh) 2018	Monthly Energy Output (kWh) 2019	Monthly Energy Output (kWh) 2020
Jan	(99,393.41)	(112,067.55)	(112,067.55)
Feb	(115,396.08)	(27,683.39)	(36,149.33)
Mar	(136,759.93)	(60,382.86)	(99,393.41)
Apr	(102,467.22)	(96,381.70)	(108,799.40)
May	(96,381.70)	(87,712.79)	(112,067.55)
Jun	(69,540.39)	(82,232.38)	(105,607.72)
Jul	(52,066.77)	(52,066.77)	(58,187.75)
Aug	(50,114.47)	(60,382.86)	(64,853.91)
Sep	(64,853.91)	(41,081.66)	(74,484.71)
Oct	(87,712.79)	(69,540.39)	(67,175.76)
Nov	(84,943.12)	(102,467.22)	(56,104.99)
Dec	(39,416.39)	(115,396.08)	(136,759.93)
Total wind energy	**999,046.18**	**907,395.64**	**1,031,737.83**

As shown in Table 3 and Figures 3 and 4 (highest production in 2020), production exceeded the gigawatt-hour mark, registering 1,031,737.83 kilowatt-hours. Production remained strong throughout the spring and summer seasons, peaking in December at 136,759.93 kilowatt-hours. while, the lowest production was in 2019, when output fell to 907,395.64 kWh. This corresponds to a low average annual wind speed (8.8 knots) and was severely affected by a sharp drop in production in February (only 27,683.39 kWh). On the other hand, the production remained stable in 2018, with total output reaching 999,046.18 kWh. Production peaked significantly in March (136,759.93 kWh), coinciding with a peak wind speed of 10.9 knots.

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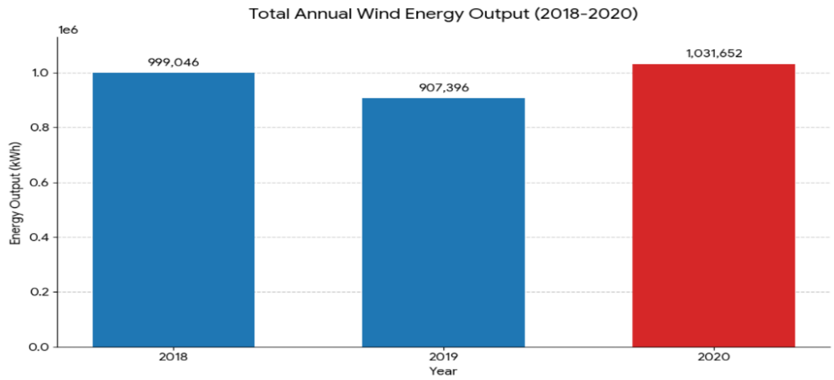

Figure 3. Total Annual wind energy output (2018 to 2020)

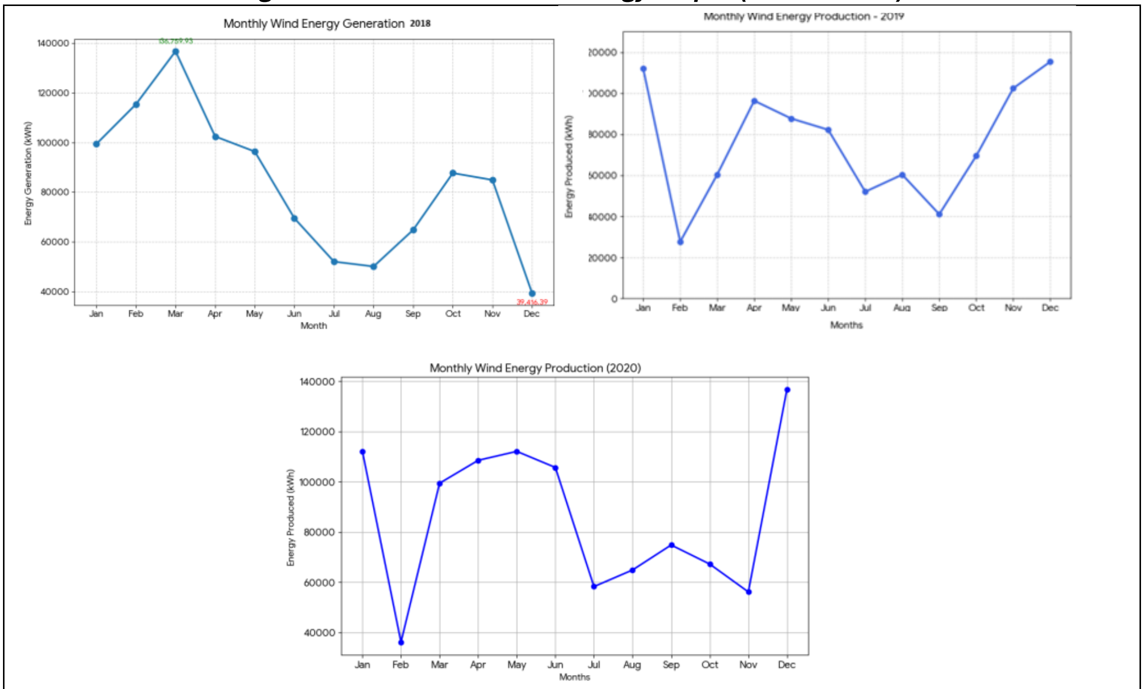

Fig 4. Wind energy production (2018 to 2020)

Weibull Distribution

Engineers and researchers widely use the Weibull distribution to perform statistical analysis of random data, such as changes in wind speed [14]. The Weibull distribution is a versatile statistical model widely used in wind power engineering to predict how frequently different wind speeds will occur at a given location. Because wind speeds are not constant, engineers use the Weibull distribution to map wind variations and accurately calculate the amount of electricity a turbine will produce over its lifetime. The Weibull distribution includes two parameters: the scale parameter (c), which relates to the average wind speed, and the shape parameter (k), which relates to the variance. These two parameters are used to find the probability density function and the cumulative distribution function, as well as the power density and energy. The wind energy probability of a location is classified according to its power density, so the accuracy of the parameter estimation method is an important factor to consider.

Summary of the analytical comparison

Table 3 below illustrates how taking actual wind distributions into account affects the overall estimates.

Table 3. Comparing a simple prototype with the sophisticated Weibull statistical model.

Metric year	Unimproved Model (flat 30-day baseline)	Statistical Weibull Model (real calendar hours)	Net Mathematical variance
2018	999,046.18 kWh	1,749,812.56 kWh	**+75.15% Increase**
2019	907,395.64 kWh	1,863,640.40 kWh	**+105.38% Increase**
2020	1,031,737.83 kWh	1,757,987.35 kWh	**+70.39% Increase**

The table above illustrates the crucial impact of statistical accuracy in wind energy modeling by comparing a simple prototype with the sophisticated Weibull statistical model. The huge variance between 70% and 105% is due to the

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unoptimized model's reliance on a fixed 30-day average, whereas the Weibull model takes into account actual calendar hours and hourly wind distribution.

Variance Analysis year by year

- In 2018, the unoptimized model predicted an output of 999,046.18 kWh, while the Weibull model revised this value to 1,749,812.56 kWh (+75.15%). This represents a typical wind distribution, where hidden gusts occurring every hour significantly increased the actual generation potential.
- The most interesting finding in the data is the high volatility in 2019. According to the unoptimized model, 2019 appeared to be the worst year (907,395.64 kWh). However, according to the Weibull model, it actually became the highest-yielding year (1,863,640.40 kWh), resulting in a massive variance of +105.38%. The reason is that, despite the low average monthly wind speeds in 2019, the site experienced sharp fluctuations and strong gusts around the clock. The Weibull shape factor (k) detected this significant energy variability, revealing that the site was actually highly productive despite the low baseline averages.
- In 2020, the winds were stable and regular, with 2020 experiencing the lowest variability (+70.39%), as production increased from 1,031,737.83 kWh to 1,757,987.35 kWh.
-

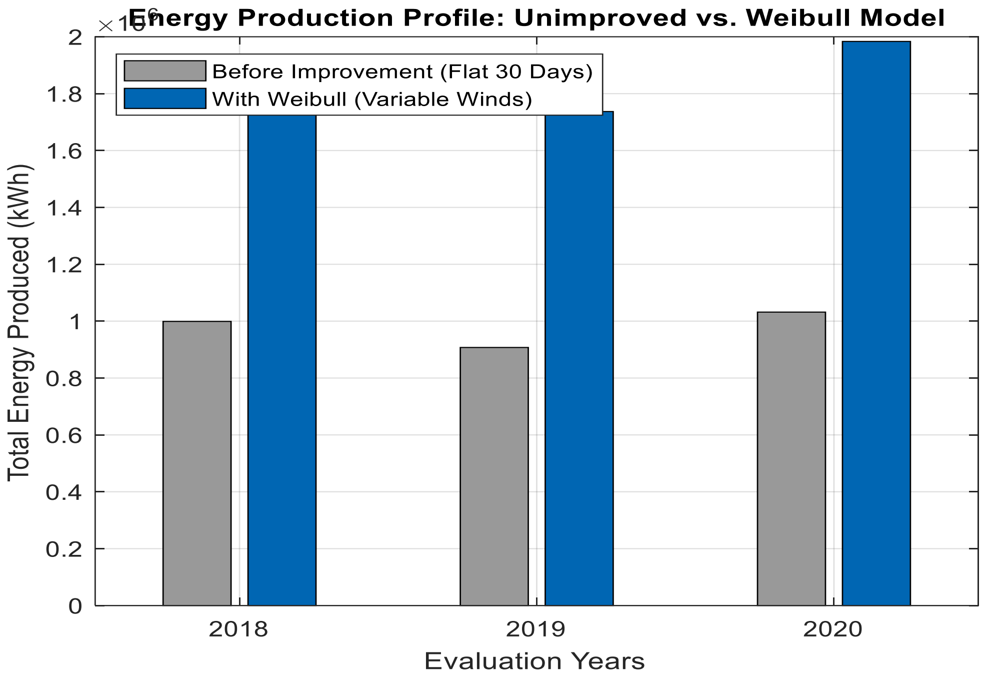

Figure 5. Energy production unimproved vs Weibull model (2018 to 2020)

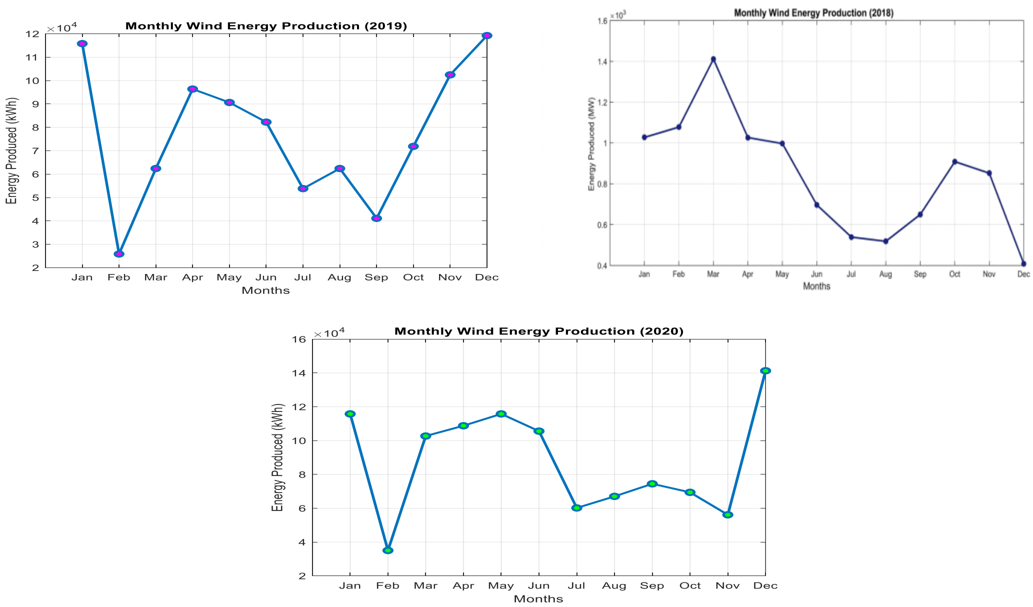

Figure 6. Wind energy production by Weibull model (2018 to 2020)

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Conclusion

Based on the results of the investigation, the following conclusions can be drawn. The highest average monthly wind speeds were recorded in March 2018 and December 2020, reaching 10.9 knots (5.607 m/s) in both. On the other hand, the lowest wind speeds were recorded in February 2019 saw the quietest period with an average wind speed of 6.4 knots (3.292 m/s). In general, Wind speeds remained relatively stable over the three years, with 2020 being the most active year in terms of wind speed. also, in 2018, the unoptimized model predicted an output of 999,046.18 kWh, while the Weibull model revised this value to 1,749,812.56 kWh (+75.15%). The most interesting finding in the data is the high volatility in 2019. According to the unoptimized model, 2019 appeared to be the worst year (907,395.64 kWh). However, according to the Weibull model, it actually became the highest-yielding year (1,863,640.40 kWh), resulting in a massive variance of +105.38%. In 2020, the winds were stable and regular, with 2020 experiencing the lowest variability (+70.39%), as production increased from 1,031,737.83 kWh to 1,757,987.35 kWh.

Conflict of interest. Nil

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